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Fungal Exposure and Shelter Assessment in Syrian Refugee Settlements in Lebanon

Malek Alaouie ^{1,*} , Gera M. Troisi ^{1,*} , Najat Saliba ² , Houssam Shaib ³, Rayan Hajj ⁴, Rawan El Hajj ⁴, Sandy Malak ⁴, Carla Jakarian ⁴ and Wiaam Jaafar ²

¹ Institute for Health, Medicine and Environments, Brunel University London, Uxbridge UB8 3PH, UK

² Department of Chemistry, Faculty of Arts and Sciences, American University of Beirut, Beirut 1107 2020, Lebanon

³ Faculty of Agriculture and Food Sciences, American University of Beirut, Beirut 1107 2020, Lebanon

⁴ Shelter, WASH and MEAL Departments, Save the Children Lebanon, Beirut 1377 2020, Lebanon

* Correspondence: malek.alaouie@brunel.ac.uk (M.A.); gera.troisi@brunel.ac.uk (G.M.T.)

Abstract: Over 1 million Syrian refugees have fled war to seek asylum in Lebanon. The population has been placed in substandard conditions which could lead to adverse health effects, particularly in vulnerable subgroups, notably due to evident chronic dampness and inadequate ventilation potentially leading to indoor mold growth. To investigate whether the types and conditions of Syrian refugee shelters influence indoor mold populations, a cross-sectional indoor environmental study was performed in 4 provinces of Lebanon. Accordingly, a total of 80 refugee households and 20 host population households (baseline) were selected. Mold air sampling and moisture measurements of shelter material were performed in residential, non-residential, and non-permanent shelters. Results revealed that although non-residential shelters had the highest mean total indoor count (1112 CFU/m³), *Aspergillus*, *Stachybotrys*, and *Penicillium* spp. were strongly associated with non-permanent shelters ($p < 0.001$). Additionally, occupancy was found to be strongly associated with *Cladosporium* ($p < 0.05$), *Ulocladium* ($p < 0.05$), and *Stachybotrys* spp. ($p < 0.001$). As for shelter conditions, the highest total indoor count (1243 CFU/m³) was reported in unfinished structures. These findings suggest that shelter category, condition and occupancy significantly influence indoor mold concentrations, increasing respiratory health risks for Syrian refugees in Lebanon.



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1. Introduction

The Syrian war has relocated over 10 million Syrian refugees of which 7.5 million are displaced internally. By 2016, the number of Syrian refugees registered with the United Nations High Commissioner for Refugees (UNHCR) in Lebanon, exceeded 1 million (equivalent to 25% of the local population), making it the third largest refugee population globally. Nevertheless, in 2017, Lebanon became the second largest Syrian refugee-hosting country after Turkey and maintained this position through 2022 [1–3].

As of June 2018, the distribution of Syrian refugees across the 4 major provinces in Lebanon, was 36% in Bekaa, 26.2% in Beirut, 25.8% in Northern Lebanon, and 12.1% in Southern Lebanon. About 47.5% of refugees are males and 52.5% are females with children under the age of 17 accounting for 55.5% of the population. The 222,695 refugee households reside in urban, suburban and rural areas [1,3,4]. While 70% of refugees live in apartments and rented rooms, 16% of households live in temporary structures known as informal tented settlements (IS), 5% reside in unfinished buildings and 9% as annexed structures to existing houses. Moreover, 44% of refugee households have 5 or more people sharing one bedroom [5]. A similar crowding occurs in neighboring countries accommodating Syrian refugees. Within the Za'atari camp in Jordan, for example, the needs of refugees

have already surpassed the camp's capacity, leading to sanitation problems and limited access to medical care [6].

Lebanon is adjacent to conflict zones and subject to regular domestic political and social unrest, resulting in issues with the dissemination of aid to refugees and a lack of economic investment to improve shelters and stakeholder conditions. Syrian refugees in Lebanon accordingly lack essential services relating to access to drinking water and sanitation, due partially to budget constraints of non-governmental humanitarian organizations and restrictions on the establishment of larger refugee camps imposed by the Lebanese government which put the refugee population at risk whereby the vulnerable subpopulation such as children, women, the elderly and immunocompromised individuals are at an even higher risk of developing respiratory and other diseases [7,8].

Building codes are developed to promote occupants' health by setting construction quality and structural integrity standards [9]. Structurally unsound units and poorly designed low-cost housing can lead to susceptibility to environmental, sanitary, and severe weather conditions [10–12]. Building products are a source of hazardous emissions and structural defects can promote pollutants pathway within dwellings [13,14]. Previous studies related to housing conditions and health in Middle East refugee camps have shown strong associations between poor housing quality and respiratory illnesses, such as asthma prevalence in children and women's health. Before the Syrian war, humanitarian research focused on internally displaced and asylum-seeking Palestinian refugees. For example, the ISAAC study in 2000, revealed that schoolchildren from refugee camps were at significantly greater risk of asthma than those from neighbouring villages and cities in Palestine [15]. In 2001, a study of 1625 households in the Gaza Strip found that the quality of environmental health and hygiene significantly influenced the occurrence of parasitic infections and dysentery particularly among children aged 1–4 [16]. A study at another Palestinian refugee camp, revealed a strong association between women's health and unhealthy housing conditions from overcrowding, inadequate ventilation and poor hygiene [17]. The clinical association between microbiological exposure and incidence of allergies, asthma, respiratory and immunological conditions in refugee camps is well recognized [18–20], but it should be borne in mind that refugees are exposed to mixtures containing volatile chemicals (including pesticides and cleaning chemicals), suspended particulates as well as airborne immunogens and pathogens, which together exacerbate health impacts. Naturally, it is very difficult to attribute causality to the exposure of a single entity and disease, and there is a paucity of research due to limited resources and local politics [21].

Natural ventilation, which is the main method adopted in refugee settlements, uses pressure differences between the indoor and outdoor air to create air exchange without mechanical intervention, thus reducing energy cost. Mechanical ventilation on the other hand, requires electrical consumption to adjust temperature and control humidity [22,23]. Both methods have their drawbacks, nevertheless. Natural ventilation in urban settings, for instance, introduces harmful pollutants from the untreated outdoor air and does not contribute to dilution of indoor contaminants concentration which according to the US EPA may be 2 to 5 times and in some cases 100 times more concentrated than outdoor air [22,24,25]. Furthermore, HVAC systems are potential sources of pollutants contributing to microbial growth resulting in condensation from heat exchange [26]. However, ventilation is not the only contributing factor to indoor air quality, building material can also be a potential source of toxicity and a medium for microbial and fungal growth [13,14,26–28].

Mold are eukaryotic microorganisms which grow filaments called hyphae [29]. They pertain to the kingdom Fungi and fall into 3 main common groups which are Zygomycetes, Basidiomycetes, and Ascomycetes, the group which contains the main fungi that colonize building materials [30]. Fungal mould growth is a major concern for architects and structural engineers which is a housing epidemic that leads to undesirable changes in the structural characteristics of buildings [31]. Fungi are ubiquitous in nature, they can be parasitic or symbiotic, however, most fungi are saprophytic, absorbing nutrients from

decaying material. In indoor environments, materials such as wood, paper, paint, insulation, and dust are suitable for fungal growth. [32] These bio-receptive materials allow the growth of fungi such as *Alternaria*, *Stachybotrys*, *Cladosporium*, *Penicillium*, and *Aspergillus* spp. [33,34]. Mould growth also depends on certain environmental conditions such as temperature and relative humidity (RH%). Mould usually favor temperatures between 15 and 30 °C, however, some species grow below or above this range [32]. As for relative humidity (RH%), a range between 30% and 50% should be maintained for a healthy indoor air (ASHRAE standard 62.1 recommends 30 and 65% RH [35]) as fungal growth and dust mite infestations occur above 50% RH [36]. Although fungal spores can travel passively through environments, indoor fungal presence is mainly attributed to moisture, and growth can occur on material with water activity varying between < 0.8 and > 0.98 [37].

In 2004, the Damp Indoor Spaces and Health Committee of the Institute of Medicine (IOM) reviewed and summarized the scientific evidence for relationships between indoor air exposure and the development and exacerbations of asthma. It concluded among several studies sufficient evidence of an association between damp indoor exposure and certain respiratory health outcomes, but insufficient evidence of an association between the presence of mold and the onset of asthma [38–40]. Conversely, the World Health Organization (WHO) concluded the level of evidence was sufficient to suggest causality for asthma development and “almost” sufficient for the exacerbation of asthma irrespective of age group [21]. Although several studies have focused on refugee health in relation to the built environment [41–48], none have investigated the evidence for correlations between categories and conditions of settlements, and the type and prevalence of airborne mold knowing that vulnerable and immunosuppressed individuals (children, the elderly, HIV patients, pregnant women, and patients on immunosuppressive medication) account for more than 60% of the Syrian refugee population which put them “at risk” from health effects from exposure to elevated levels of pathogenic fungi [49–53]. Such information is vital to refugee management for planning locations and types of settlements according to season, resources, refugee demographics (composition and proportion of vulnerable groups) and refugee health status. The aim of this study is thus to investigate correlations between mold concentrations and the categories, structural conditions, occupancy and moisture content of Syrian refugee shelters to evaluate the influence of each of these factors on total indoor mold counts and abundance of specific mold genera.

2. Materials and Methods

2.1. Population Data

An original sample size representing the total number of registered refugee households by UNHCR was calculated to be 97 and rounded to 100 households with a 95% confidence interval and a 10% error margin. Access to refugee households was limited by geographical, logistical, and communication challenges. Consent for accessing the shelters was obtained on the same day of sampling by each head of household. The sample size was accordingly reduced to 80 refugee households due to these limitations. While random selection was the method of recruitment, only Syrian refugee households residing in the identified settlements were selected since other nationalities were also present, however, did not share the current humanitarian and socio-political profile of refugees governed by forced displacement and constricted temporary residency. Furthermore, an effort was made to obtain a close representation of shelter classifications under residential, non-residential, and non-permanent shelters (Table 1). Settlements were selected from four Lebanese governorates using the beneficiaries’ database of Save the Children in Lebanon. Households were anonymized and referenced as per Save the Children’s internal Memoranda of Understanding established with the beneficiaries.

Table 1. Distribution of Sampled Refugee Households ($n = 80$).

Governorate	Area	No. Households	Residential	Non-Residential	Non-Permanent
Beirut	Bourj Hammoud	20	20		
Bekaa	Bar Elias	20	2		18
South	Abra	20	7	13	
North	Biret Akkar	20		20	

The selected sample included non-residential (41.25%), non-permanent (22.5%), and residential (36.25%) households. Non-residential households included classrooms, garages, and storerooms; residential households included rented apartments and rooms in multi-family buildings, while non-permanent households were informal tented settlements, composed of detached structures made from timber, plywood ceilings and walls, draped with cloth and plastic sheets (Figure 1). The floor area of these structures was approximately 45 m² for single-family households and 100 m² for multi-family households. The average occupancy per household in all refugee shelters was 6 persons and children accounted for more than 50% of the selected population. As for the control group, 20 residential standard apartments were selected from the host population, representing indoor baseline conditions, whereby 10 apartments were located in Beirut and 10 in Mount Lebanon. Accordingly, the total sample size was 100 households with a 4:1 refugee to baseline control ratio. The cross-sectional study covering sampling and moisture assessment was performed in the spring season (May 2019).



Figure 1. (Left) Aerial views of the Bourj Hammoud neighborhood in Beirut. (Right) and informal tented settlements in the Bekaa Bar Elias region.

The selected households were naturally ventilated through windows in residential and non-residential shelters, while non-permanent shelters (informal settlements) relied on natural air infiltration through structural gaps and guided exhaust from small wall-mounted fans. Shelters were further categorized based on structures such as concrete or wood, and on conditions such as “Standard”, “Damaged”, “Unfinished”, or “Visible Mold” (Table 2). Standard shelters are mainly residential apartments with intact structural integrity. Damaged shelters, on the other hand, are any type of shelter that has cracks in walls and/or ceilings, and/or a leaking roof. Unfinished shelters were rooms lacking insulation, floor tiles and/or paint primer. The presence of visible mold patches was considered evidence of fungal growth on building surfaces.

Table 2. Shelter Condition.

Shelter Category	Standard	Damaged	Unfinished	Visible Mold
Residential <i>n</i> = 29	5	1	4	19
Non-residential <i>n</i> = 33		13	20	
Non-permanent <i>n</i> = 18				18

2.2. Mold Air Sampling and Enumeration

A walkthrough inspection was performed in every household prior to sampling [54]. Photographs of building structural integrity and conditions were taken, including visible mold growth. Most shelters consisted of a single room and adjacent connected cooking area and a shared toilet with low or absent interior walls. Images of visible mold growth typically seen on residential and informal settlement walls and ceilings are shown in Figures 2 and 3.

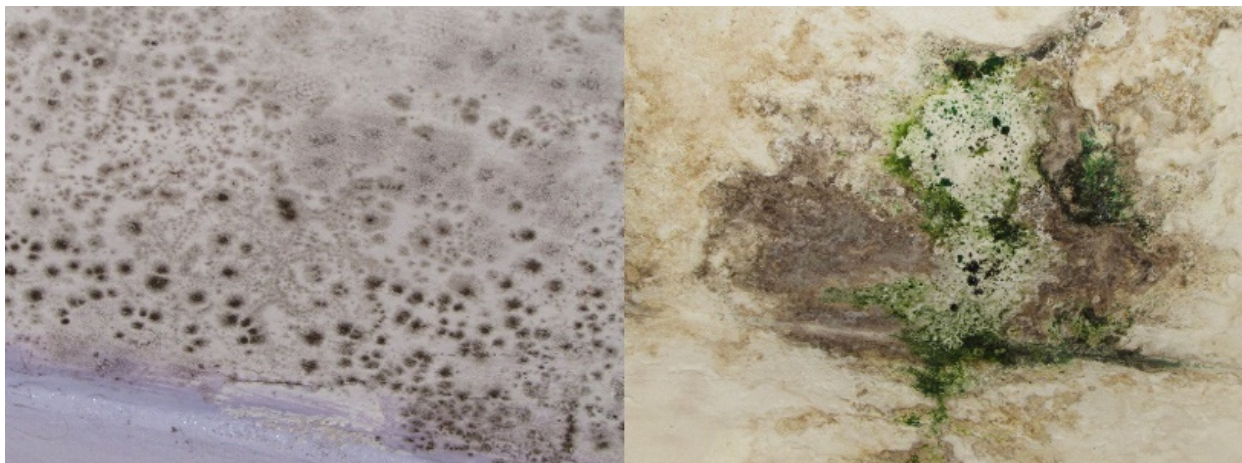


Figure 2. Examples of evident sporadic (**left**) and concentrated (**right**) mold growth on residential shelters ceilings.



Figure 3. Example of mold growth on the ceiling (**left**) and wall (**right**) wood panels inside informal settlements.

An Andersen N6 single-stage impactor, consisting of 400 precision holes of 0.65 μm cut-off diameter was placed on a tripod in the middle of the selected room at 1.5 m above

the ground [55]. The impactor was connected to a Zefon® pump adjusted to 28.3 Liter per minute (L/min) with 9 mm Sabouraud dextrose agar media plates placed inside the impactor to collect samples. A total of 2 samples were taken for 5 min and another 2 for 2.5 min according to ISO standard methods (ISO 16000-17) [56,57]. An ambient outdoor and a blank sample were collected to establish the ambient baseline concentrations for each monitoring exercise. Control (field blank) samples were processed alongside samples and treated in an identical manner for quality control [56]. Samples were incubated at 25 °C on the day of collection and observed for colony growth at 24, 48, 72 and 96 h. Enumeration was performed before the overgrowth of colonies. Positive hole correction to calculate a probable count from the total raw count (assuming multiple particles can impact the same hole) was applied to total counts before conversion to colony-forming units per cubic meter (CFU/m³) [56,57]. Positive hole correction was calculated using the following formula:

$$Pr = N [1/N + 1/N - 1 + 1/N - 2 + \dots 1/N - r + 1]$$

where;

Pr is the expected number of viable particles to produce 'r' positive holes.

N is the total number of holes which is 400 in the case of the Andersen N6 single-stage impactor.

Sampled volumes at 5 and 2.5 min were 141.5 L and 70.75 L, respectively. The concentration of colony-forming units per cubic meter of air C_I was calculated for each sample according to the following formula [57]:

$$C_I = \frac{n_{CFU}}{V_I}$$

where;

n_{CFU} is the total number of colony-forming units on the agar plates.

V_I is the total sampling volume, in cubic metres.

To calculate the total concentration of molds in each location, the 4 sampled volumes (2×141.5 L and 2×70.75 L) were added, as per the following formula:

$$C_I = \frac{n1_{CFU} + n2_{CFU} + n3_{CFU} + n4_{CFU}}{V_{I1} + V_{I2} + V_{I3} + V_{I4}}$$

The indoor/outdoor ratio (i/o) was calculated by dividing the total indoor count by the total outdoor count after positive hole correction adjustment.

2.3. Identification of Mold/Fungi

For the identification of indoor mold genera, a sample from distinctive colonies on the Sabouraud dextrose agar was taken by means of an inoculating loop and placed on alcohol covering the center of the microscopic slide. A total of 3 drops of lactophenol cotton blue were used to stain the fungal culture and a cover slip was placed over the sample. Slides were gently heated before microscopic examination at 100, 40 and 20× magnification to identify mold genera. Microscopic structures were identified using the Atlas of Clinically Important Fungi and the Pictorial Atlas of Soil and Seed Fungi [58–60]. Enumeration of specific mold type was reported as CFU/m³, for the purpose of establishing possible correlations between mold genera, and type and conditions of shelters.

2.4. Moisture Content

The moisture content of shelter material was determined using a Tramex® non-destructive moisture meter using a scale of 5–30% moisture for wood structures and 0–100% scale for concrete structures. For concrete structures, an average of three readings was taken for study locations around windows, on shelter floors and walls adjacent to frequently damp environments (e.g., bathrooms and kitchens). For informal settlements, moisture was measured on wood structures (e.g., beams and ceiling panels). Readings

were collected once the device was firmly placed against the structure and moved around until the highest reading was recorded [61].

2.5. Data Analysis

Descriptive statistics were used to determine the percentages of each mold present within a household. Analysis of variance (ANOVA) was used to determine the statistical significance of any differences between mean mold concentration, indoor/outdoor (I/O) mold ratio and total indoor count (TIC), among different types of shelters. ANOVA was also used to determine the statistical significance of any difference between the above-mentioned variables among different observed shelter conditions.

Barlett's test for equality of variances was used to account for unequal sample sizes.

Pearson correlation was used to determine associations between moisture content in concrete for residential and non-residential shelters, and wood for non-permanent shelters and the following parameters:

- Concentration of different mold types
- I/O ratio
- Total indoor count
- Occupancy

The adjusted p -value for all parts was determined using a regression test. The significant model with high R^2 and adjusted R^2 was considered the final one.

To account for outliers in the selected sample, non-parametric analysis using the Kruskal–Wallis test was conducted to determine the correlation between TIC and type of shelter.

Similarly, robust regression was used to determine the correlation between TIC and occupancy.

3. Results and Discussion

3.1. Mold Concentration

Aspergillus, *Cladosporium*, *Penicillium*, and *Rhizopus* spp. were the most prominent genera in the 3 shelter categories and baseline households (Figure 4). The results revealed that non-permanent shelters had the highest concentrations of *Stachybotrys* (8.6 CFU/m³), *Aspergillus* (64 CFU/m³), *Penicillium* (223.4 CFU/m³), *Pithomyces* (7.5 CFU/m³) and *Ulocladium* (3.9 CFU/m³) spp., indicating that the shelter structure influenced the abundance of these genera. Furthermore, *Cladosporium* and *Alternaria* spp. ($p < 0.01$) were more abundant in non-residential compared to non-permanent and residential shelters, and significantly higher than baseline households. A final regression model ($R^2 = 56.32\%$) established between types of shelter and the most abundant mold genera revealed a significant association ($p < 0.001$) with *Aspergillus*, *Penicillium*, and *Stachybotrys* spp., which may be considered as predictors of informal architecture and design.

Rhizopus spp. was higher in non-residential shelters compared to other categories, followed by controls, however, no significant association was found. The presence of *Rhizopus* in control households may indicate that seasonal and psychometric factors influence airborne concentrations, more than building material [62,63]. Additionally, despite the low concentrations of *Candida* spp. in all types of shelters, controls were found to have the highest counts and no significant association with refugee shelters. As seen with *Rhizopus* spp., *Candida* spp. abundance was attributed to factors unrelated to building structure, such as indoor emissions and/or human activity [58].

Health effects attributed to mold exposure include fungal infections, allergic rhinitis, asthma, hypersensitivity pneumonitis, interstitial lung disease, bronchopulmonary aspergillosis, allergic fungal sinusitis, and organic dust toxic syndrome. The illnesses and symptoms caused by such exposure range from flu-like syndromes and congestion to interstitial or cavitary pneumonia and fibrosis [32,64–66]. Furthermore, some of the identified genera, particularly *Aspergillus* and *Penicillium* spp., produce secondary mycotoxins such as aflatoxins and ochratoxins which can cause adverse health effects in exposed

humans [67–69]. Table 3 summarizes major symptoms and diseases associated with mold exposure, adopted from Storey et al. (2004) Guidance for Clinicians [32]:

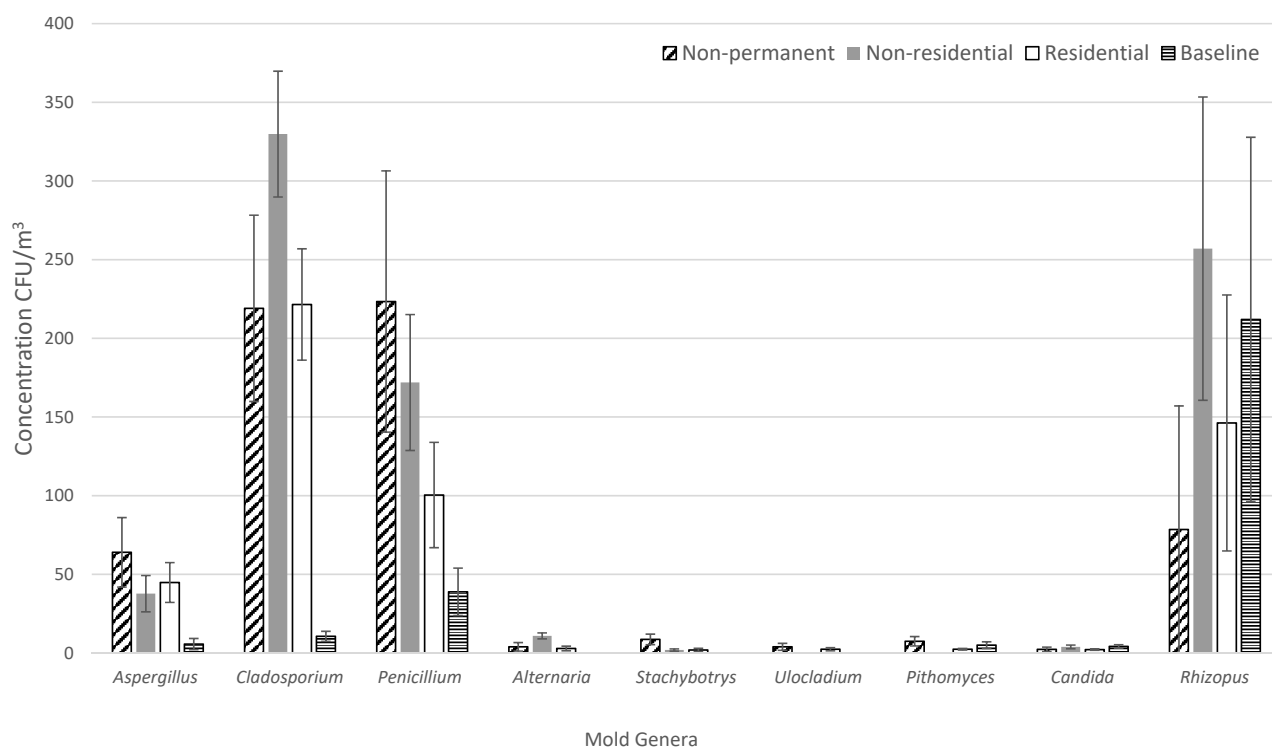


Figure 4. Indoor mold by type of shelter, mean concentrations (\pm std. error). Non-permanent ($n = 18$); non-residential ($n = 33$); residential ($n = 29$); baseline households ($n = 20$).

Table 3. Clinical Outcomes of Mold Exposure.

Health Effects	Illness/Symptoms
Fungal Infections	Flu-like syndrome, interstitial or cavitory pneumonia, meningoencephalitis, tinea cruris, corporis, and pedis.
Allergic Rhinitis and Asthma	Upper airway: clear rhinorrhea, nasal congestion, sneezing, post-nasal drip with sore throat, coughing, and hoarseness. Lower airway: bronchospasm, chest tightness, and shortness of breath.
Hypersensitivity Pneumonitis and Interstitial Lung Disease	Extrinsic allergic alveolitis, farmer's lung, Japanese summer-house, cryptogenic fibrosing alveolitis, idiopathic pulmonary fibrosis.
Bronchopulmonary Aspergillosis	Eosinophilic pneumonia, mucous plugs, or asthma exacerbations.
Allergic Fungal Sinusitis	Polyposis
Allergic Dermatitis	Dryness, pruritus, and skin rashes.
Irritation	Cough, skin irritation, and burning or itching of the eyes and nose.
Organic Dust Toxic Syndrome	Flu-like syndrome with prominent respiratory symptoms and fever.

Simoni et al. (2005) reported a strong correlation between early childhood mold exposure and the onset of respiratory disorders and asthma, more evident in children than adolescents [70]. Furthermore, the Leipzig Allergy Risk Children Study (LARS) suggested a significant association between respiratory tract infection and exposure to *Penicillium* spores $> 100 \text{ CFU/m}^3$, and between allergic rhinitis and exposure to *Aspergillus* $> 100 \text{ CFU/m}^3$ in 200 children aged 36 months [71].

The majority (67%) of identified mold genera are commonly found in air samples of moisture-damaged dwellings and in bulk samples of water-damaged building material [72,73]. Damaged structures had the highest concentrations of *Aspergillus* and *Alternaria* spp. ($p < 0.05$) compared to standard, unfinished and visibly mold-infested shelters. *Cladosporium* spp. was highest and equally abundant in damaged and unfinished shelters and lowest in standard shelters ($p < 0.001$). Compared to standard, damaged and visible mold-infested shelters, unfinished shelters had the highest concentrations of *Penicillium* and *Rhizopus* spp., however, this was not statistically significant (Figure 5).

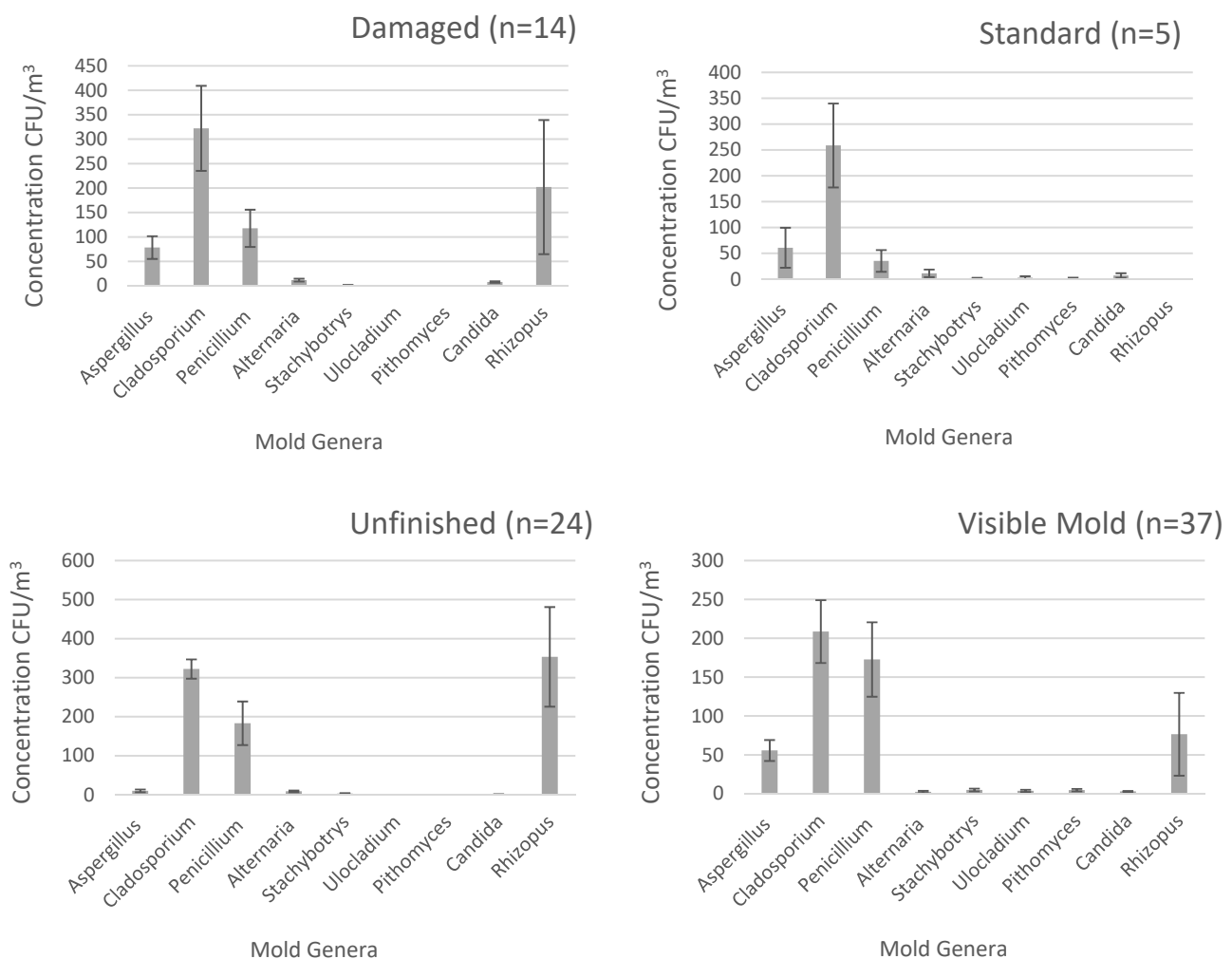


Figure 5. Indoor Mold Abundance by Shelter Condition (mean \pm std. error).

Among the 9 identified fungal genera, only *Cladosporium* ($p < 0.05$), *Stachybotrys* ($p < 0.001$), and *Ulocladium* ($p < 0.05$) spp. were significantly associated with occupancy (Table 4).

There were no significant correlations between concrete moisture content and mold concentrations, except for *Aspergillus* spp. ($R^2 = 14.2\%$, $p < 0.001$), *Penicillium* spp. ($R^2 = 7.6\%$, $p < 0.05$), and *Cladosporium* spp. ($R^2 = 9.3\%$, $p < 0.05$). However, a significant correlation was observed between moisture content in wood and *Stachybotrys* spp. ($R^2 = 24.3\%$, $p < 0.05$).

only (Figure 6). Although wood is used alongside concrete and other building materials in residential and non-residential structures, it is the predominant material in non-permanent shelters and unlike other shelter categories, it is exposed to moisture and environmental conditions. The abundance of *Stachybotrys* spp. in non-permanent shelters could hence be attributed to the bioreactivity of exposed wood and timber and would lead to material biodeterioration as well as health implications [37,74,75].

Table 4. Correlation between mold concentrations and occupancy.

Genus	Occupancy	<i>p</i> -Value	R ²
<i>Aspergillus</i>	0.075	0.461	0.6%
<i>Cladosporium</i>	0.215	0.032 *	4.6%
<i>Penicillium</i>	−0.015	0.879	0.02%
<i>Alternaria</i>	0.077	0.448	0.6%
<i>Stachybotrys</i>	0.337	<0.001 *	11.3%
<i>Ulocladium</i>	0.216	0.031 *	4.7%
<i>Pithomyces</i>	−0.033	0.745	0.1%
<i>Candida</i>	−0.033	0.743	0.1%
<i>Rhizopus</i>	0.014	0.893	0.02%

* *p*-value less than 0.05 is considered to be significant.

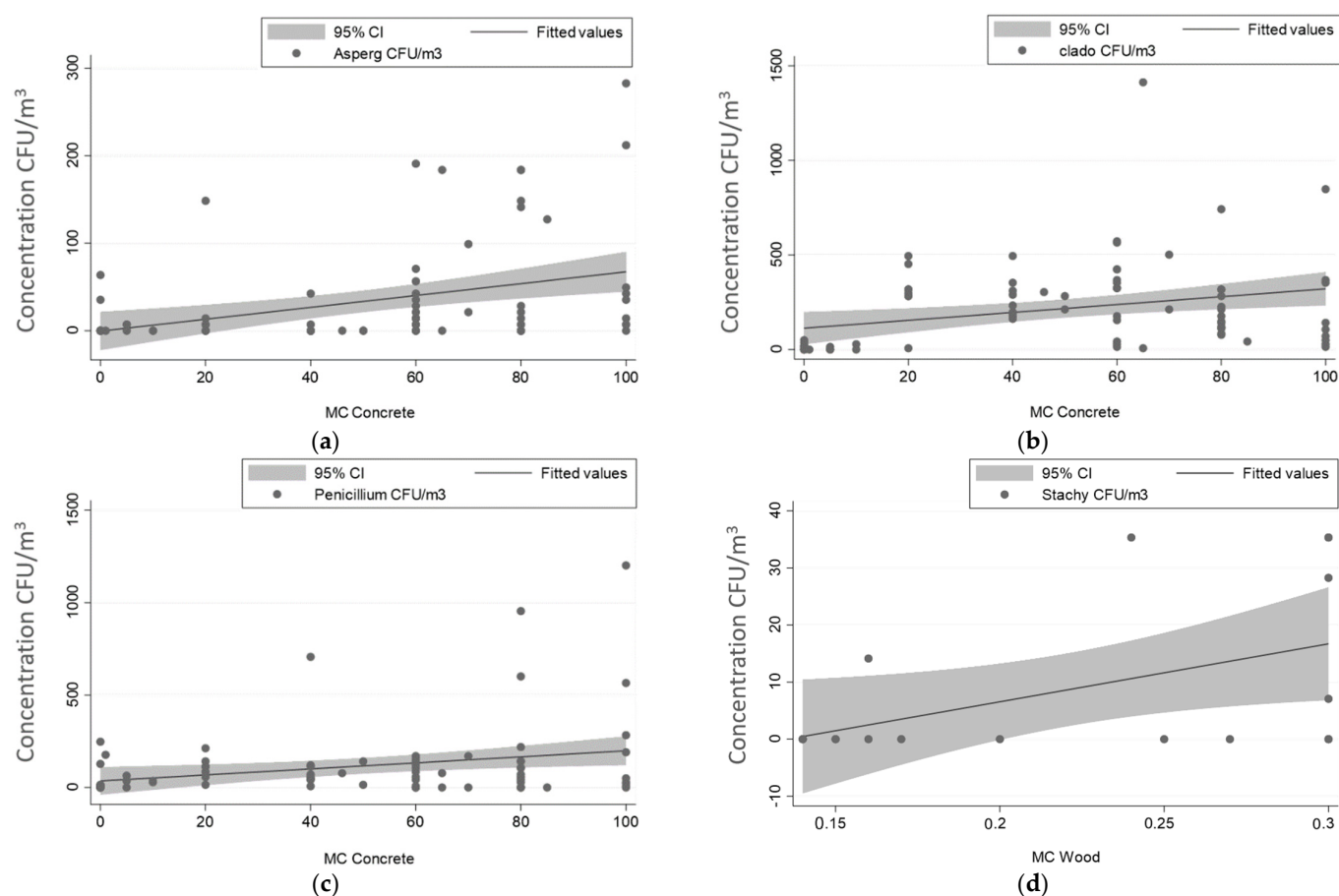


Figure 6. Confidence interval (95%) for relationship model between moisture content in shelters and concentration of *Aspergillus* spp. (a), *Cladosporium* spp. (b), and *Penicillium* spp. (c). Graph (d) represents confidence interval (95%) for regression model between moisture content in wood and concentration of *Stachybotrys* spp.

3.2. Total Mold Indoor Count

Mean TIC was highest in non-residential (1112 CFU/m³), followed by non-permanent (782 CFU/m³) and residential (733 CFU/m³) shelters (Figure 7). The Kruskal-Wallis test revealed a significant association between TIC and the type of shelter ($p < 0.05$).

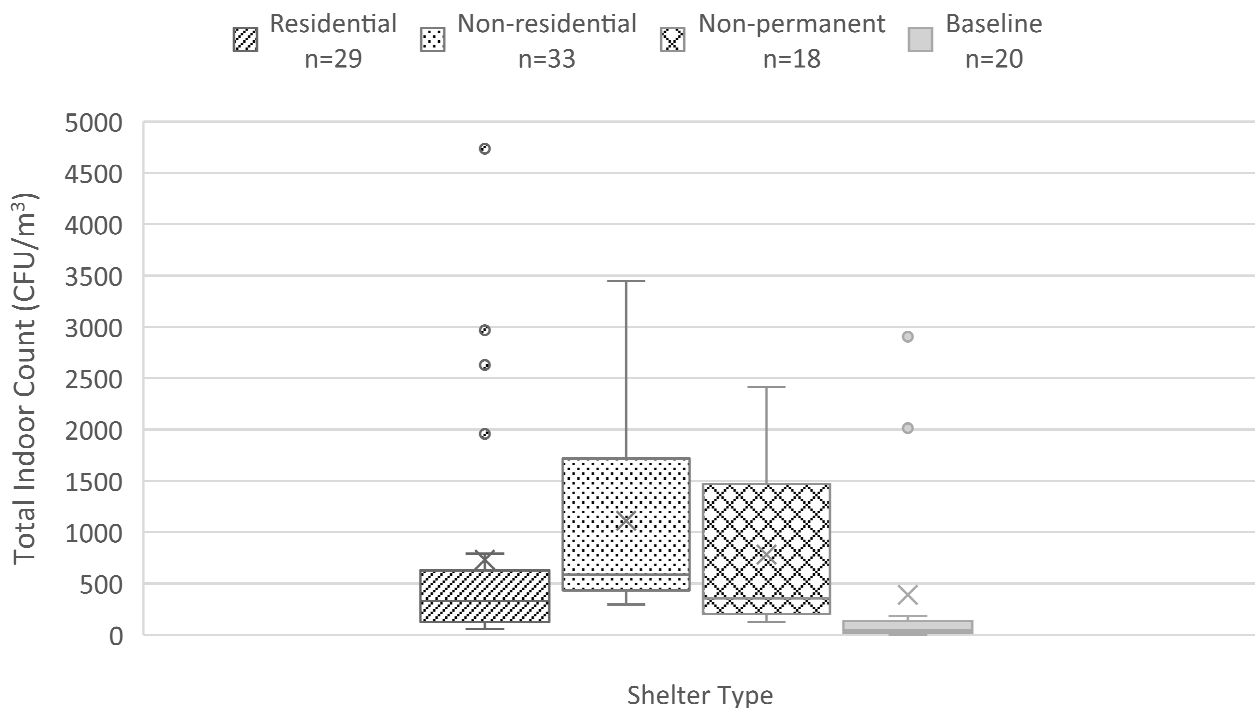


Figure 7. Mean total mold indoor count for each shelter type (Mean, depicted by the “x” mark; (range) CFU/m³). Residential (733; (57–792)). Non-residential (1112; (297–3449)). Non-permanent (782; (127–2417)). Baseline households (389; (0–184)).

Mean TIC (Figure 8) was significantly highest (1243 CFU/m³) in unfinished shelters and lowest (411 CFU/m³) in standard shelters ($p < 0.05$). Furthermore, robust regression performed to account for outliers in the sample also revealed a significant association between TIC and occupancy ($p < 0.05$).

The outdoor air of the Bekaa region, where non-permanent settlements are established, had the second highest mold count compared to other regions which could be caused by outdoor concentrations of mold spores, reflecting higher infiltration and slow cross-flow ventilation guided by exhaust fans inside the tents. The winter storms of (2018–2019) caused flooding of shelters in most regions of Lebanon which damaged construction materials especially non-permanent shelters. Poor building design of some residential and non-residential shelters resulted in plumbing leaks and permeability of surfaces to moisture, further exacerbating absorbance and retention in shelters. Nevertheless, one of the sources of indoor mold growth, as determined from walkthrough observations of the settlements, could be attributed to excessive moisture and dampness from human activity. This was mainly observed in indoor line drying of laundry and wet floors from cleaning, dripping laundry, bathing, and accidental spillage, all of which contribute to ambient humidity following evaporation (Figure 9).

This was also evident as reflected by the significant association ($R^2 = 23.63\%$, $p < 0.001$) between moisture content in concrete material and occupancy (Figure 10) suggesting that human activity and indoor practices could influence moisture content in residential, non-residential, and standard shelters where concrete is the predominant building material. Nevertheless, the low R^2 value indicates that occupancy reflected by human activity is just one of the factors affecting moisture content in structural material. The sampled shelters

are architecturally different from each other and their susceptibility to moisture or water intrusion is determined by their design, age, and exposure to environmental factors [76,77].

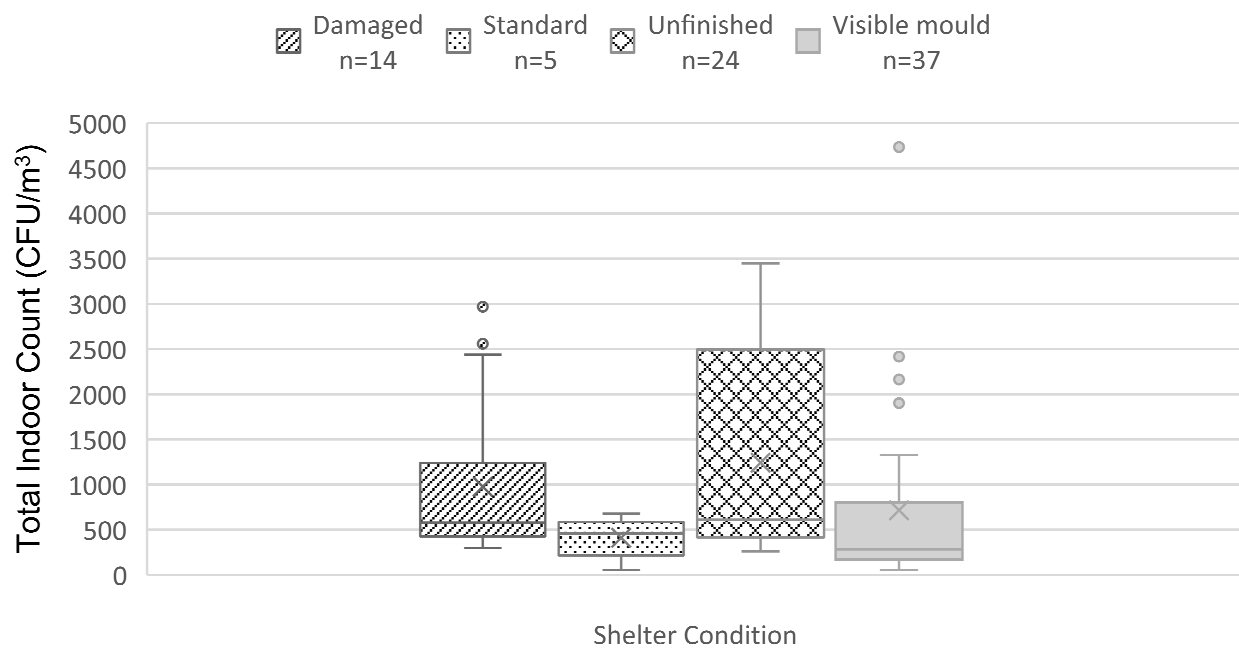


Figure 8. Mean total mold indoor count by the condition of shelter with lowest and highest concentrations (Mean, depicted by the “x” mark; (range) CFU/m³). Damaged (977; (297–2438)). Standard (411; (0–678)). Unfinished (1243; (261–3449)). Visible mould (715; (57–1329)).



Figure 9. Line drying of laundry inside residential (c) and non-residential (a,b) shelters.

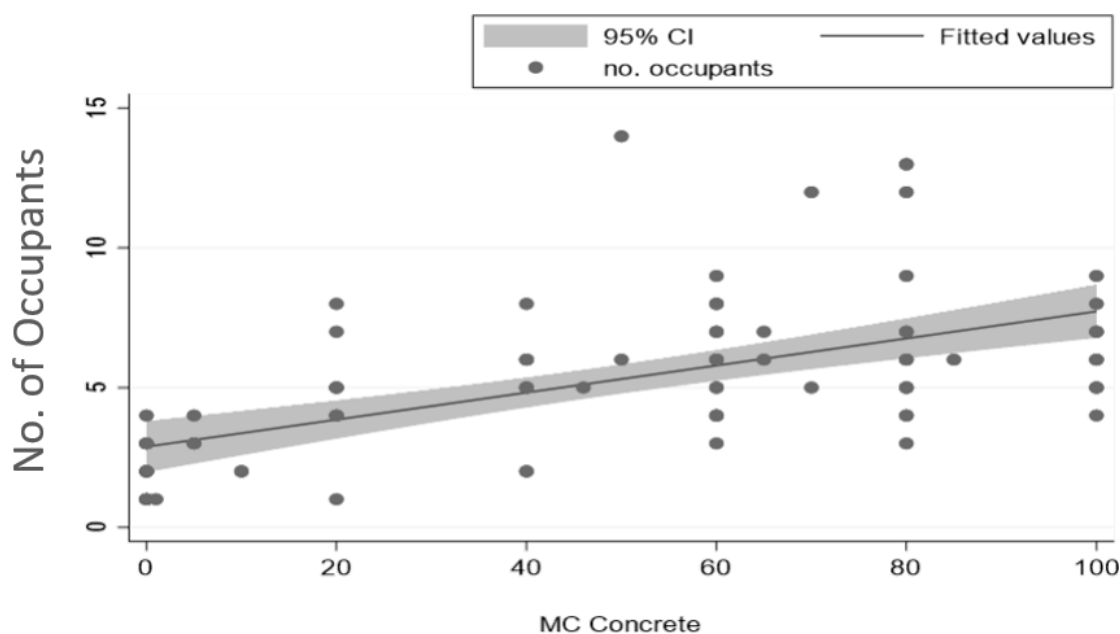


Figure 10. Confidence interval (95%) for regression model between moisture content in concrete and occupancy ($R^2 = 23.63\%$).

The concern for inadequate ventilation and human activity in self-built shelters was also reported in a study conducted in 6 countries including Turkey and Jordan which host Syrian refugees. Results revealed high concentrations of total volatile organic compounds (TVOC = $102,400 \mu\text{g}/\text{m}^3$) and particulate matter (PM = $3000 \mu\text{g}/\text{m}^3$) mainly attributed to cooking, smoking and poor aeration of the indoor environment [78].

3.3. I/O Ratio

The mean I/O ratio was higher than 1 in all sampled environments including controls. The ratio was highest in residential shelters (10.1) followed by baseline households (10.9) and non-residential shelters (3.6), and lowest in non-permanent shelters (1.8), with no significant association with types of shelters. In relation to shelter condition, the I/O ratio was highest in structurally damaged shelters (13.8) followed by standard (9.6), visible mold (6.8), and unfinished shelters (4.4), with no significant associations, however. No association between moisture content and the I/O ratio was concluded. As for occupancy, there was a slightly negative correlation with the I/O ratio.

The outcomes can be attributed to the fact that outdoor concentrations vary depending on several factors and vastly influence the I/O ratio. Outdoor conditions due to weather or activity may suppress the release of spores from outdoor sources leading to higher indoor concentrations albeit indoor sources of potential fungal growth may be absent [79]. Additionally, the exceedances in I/O ratios could be due to single-sided ventilation prevalent in residential shelters compared to other categories [21].

Although mold is present in non-refugee households, sources of moisture are often remediated in residences with better socioeconomic status. Refugees, on the other hand, lack the privilege of improving living conditions, mainly due to prioritization of expenditure. Since remediation can be costly to refugee households and non-governmental agencies, household demographics and medical conditions should be taken into consideration during shelter assignment. Some remediation measures, however, are less costly than others such as in the case of non-permanent shelters where replacing water-damaged porous material such as wood could potentially reduce mold in indoor air. Finally, considering the large refugee population size vis-à-vis the availability of standard shelters, NGOs should focus on securing budgets to standardize the living conditions of refugee households and prioritize those with immunocompromised members. Accordingly, efforts must be

made to develop a universal design for temporary shelters, accounting for ventilation and psychrometric requirements for human occupancy.

4. Conclusions

This study revealed several significant associations between categories of shelter and mold concentrations and has further established strong associations between certain mold types and shelter conditions. The aim of this study was to identify environmental risks associated with Syrian refugee shelters in Lebanon, focusing on indoor mold populations, and for NGOs to present local authorities and policymakers with scientific evidence of alarming nature and address a public health concern that may add to the existing burden on the national health system.

The shelter conditions in which Syrian refugees are residing are potential sources of diseases related to mold exposure. Several studies and international agencies including the World Health Organization have recommended remediating the sources of moisture and dampness to prevent microbial growth [21,80,81]. Cooperation, collaboration and international investment from humanitarian agencies and policymakers are imperative to establish adequate housing to protect the health and well-being of Syrian Refugees.

5. Limitations and Future Research

The study did have its limitations, more specifically, data was inherently impacted by outliers which require future studies to expand the sample size and account for indoor and outdoor influencing factors for mold. The study did not address seasonal variation in mold concentrations as it was performed only in the Spring season. Additionally, moisture content and dampness should ideally have been assessed more frequently to better reflect extreme weather events such as flooding over the winter period preceding sampling, as this increases background moisture levels. The I/O ratio should also be established for identified mold genera as the study only reported total outdoor counts without details on outdoor populations. Nevertheless, indoor microorganisms and dampness will persist in Syrian Refugee shelters in Lebanon and will worsen without proper intervention including improved ventilation and dilution. This investigation shows the vulnerability of shelters to climatic and environmental factors which worsen living conditions and indoor air quality. Further epidemiological studies, including in-depth investigation of fungal species and reported illnesses, are thus needed to determine the quantitative impact of these factors on the health of refugees, involving the cooperation of all stakeholders, particularly clinicians with access to health information for refugees, to determine whether indoor air quality is significantly influencing the health and wellbeing of this population.

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